TITLE: Comparative Evaluation of Three Different Adhesive Restorative Techniques on Fracture Resistance of Simulated Immature Permanent Teeth After Apexification- An In-Vitro Study

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 *Abstract*

*The study aimed to compare the reinforcement effect of 3 different adhesive restorative techniques on simulated immature maxillary central incisors after apexification****.*** *A total of 30 simulated immature permanent maxillary central incisors were randomly assigned into 3 groups (n=10), according to the reinforcing technique used: Group 1: Nanohybrid composite. (Tetric N-Ceram Ivoclar Vivadent), Group 2: Short-fiber reinforced composite (everX posterior GC EUROPE) extended 3mm below CEJ, covered with 1mm layer of Nanohybrid composite, Group 3: polyethylene fibre (Ribbond Inc., Seattle, WA, USA)) along with Short-fiber reinforced composite (everX posterior GC EUROPE), covered with a 1mm layer of Nanohybrid composite. These specimens were subjected to a compressive load at a speed of 0.5 mm/min and 135-degree angle along the long axis of the tooth using a Universal testing machine. Data obtained were analysed using One-way analysis of variance followed by post hoc analysis using Tukey’s test. Results showed that the mean load required for fracture of the samples were as follows: Group1-273.8000±103.35099N, Group 2- 469.4800±165.4N, Group 3-451.5100 ± 148.04774N. The highest mean fracture load value was found in Group 2. Group 1 showed significantly lower fracture resistance compared to Group 2 (p-0.012) and Group 3(p-0.024). There was no significant difference in mean fracture loads between Groups 2 and 3. Intra-coronal and intra-radicular reinforcement using Short-fibre reinforced composite and Intra-coronal reinforcement using a combination of poly ethylene fibre with Short-fibre reinforced composite showed significant improvement in fracture resistance of immature permanent teeth after apexification.*

***Keywords:*** *Fiber-reinforced composite, Fracture resistance, Immature teeth, Poly ethylene fibre.*

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**INTRODUCTION**

Traumatic dental injuries are the 5th most prevalent disease worldwide and represent one of the primary causes of tooth loss and pulp necrosis in adolescents and children. Anterior teeth are more prone to trauma, and their long-term survival after root canal therapy is often questionable due to their thin dentinal walls and associated higher risk of fracture, particularly in the cervical area **(1).** Three-dimensional finite element analysis of the maxillary central incisors demonstrated that higher stress concentrations were observed in the crown and cervical regions due to their thin dentinal walls in the cervical area, leading to cervical root fracture **(2)**. Apexification and revascularisationare recommended to treat immature teeth with pulp necrosis **(3)**. Apexification is a viable option in managing nonvital immature permanent teeth**. (4)** The prognosis of endodontically treated teeth depends not only on the treatment but also on the quality of coronal restorations that directly impact the survival of endodontically treated teeth (**5**). Post-endodontic restorations prevent cervical root fractures in weaker thin-walled teeth **(6).**

The advancements in adhesive technology and the improved strength of newer composites aid in conservative and esthetic restorations **(7).** These newer materials and techniques enable the practitioner to approach the existing problems from a different perspective and achieve unique and innovative solutions. The reinforcement of composite restorations with fibrous assemblies can change the effective fracture strength of the teeth **(8)**. Composite resin restorations adhere to the tooth structure and strengthen the tooth, thereby reinforcing weakened tooth structure **(9).** The use of fibre-reinforced composites has increased toughness and impact strength, thereby enhancing the fracture resistance of restored teeth **(10).**When fibres like polyethylene and glass are used, they act as a stress reliever for composite resins and show increased resistance to fracture and flexural strength **(11).** Polyethylene fibre inserted into a bed of flowable composite has been used in various direct restorative techniques in endodontically treated teeth which include lining the fibre under the composite filling **(7)** or over the finished composite restoration by preparing a groove **(12)** or applying the fibres inside the axial walls circumferentially **(13).**

**Roghanizad and Jones**, first proposed the replacement of 3 mm of gutta-percha with restorative material from the root canal orifice to prevent coronal microleakage and improve fracture resistance **(14).** To our knowledge, limited literature is available evaluating fracture resistance of simulated immature permanent teeth reinforced with different adhesive restorative techniques after Bio-dentine apexification. Considering these factors, the study aimed to compare the reinforcement effect of 3 different adhesive restorative techniques on simulated immature maxillary central incisors after apexification using a Universal Testing Machine.

**MATERIALS AND METHODOLOGY**

The sample size calculation was done following the pilot studyusing the G\*Power (3.1.92) software with 80% power and 5% significance.

A total of Thirty intact human maxillary central incisors extracted for periodontal reasons were selected for the study. Preoperative radiographs were made in mesiodistal and buccolingual directions to ensure the presence of a single canal and any other endodontic abnormalities. The samples were examined under a dental operating microscope at 10x magnification to confirm the absence of any pre-existing cracks. Hard and soft tissue debris was removed with an ultrasonic scaler and stored in distilled water at room temperature until use to prevent dehydration.

For standardisation, the Bucco-Palatal (BP) and Mesio-Distal (MD) dimensions of each sample at the level of the cemento-enamel junction were recorded with the use of a digital calliper. Then the samples were evenly distributed to each of the 3 groups **(15).** To standardise the length of the crown, the incisal edges of all teeth from all groups were cut with a diamond disc under water cooling to a length of 8 mm from the Cemento-enamel junction (CEJ). The roots were cut 10 mm apical to the CEJ to simulate an immature tooth with an open apex **(1).** Access cavity preparation was done using a #2 Round bur (Dentsply-Maillefer, Tulsa, Oklahoma, USA) in a highspeed handpiece under water coolant. Canal patency was checked with a #10 hand file (Mani Inc, Tochigi, Japan) to the full length of the tooth **(1).** Canal space was enlarged with Gates Glidden drills and Peeso reamers from sizes 1 to 5 (Mani Inc, Tochigi, Japan) so that a size 5 Peeso reamer could easily pass 1 mm beyond the apex to stimulate immature teeth. Root canals were irrigated with distilled water during instrumentation. A size 6 Peesoreamer was used to extend the canal preparation 3mm apical to CEJ to simulate Cvek’s stage III root development **(16).**

The canals were completely dried with size 80 absorbent paper points. Suitable Hand pluggers (Waldent Instruments,Delhi, India) were selected, and a radiograph was taken by inserting the plugger into the canal. Bio-dentin (Septodont USA) was mixed with an auto mixer (Septodont USA) and placed in increments in the apical region of the canal. Bio-dentin was condensed with light pressure using pre-fitted hand pluggers till 4mm canal was filled from the apex **(25).** The homogeneity and thickness of the apical plug were confirmed with 2 radiographs in both the mesiodistal and buccolingual directions.

The samples were randomly divided into 3 groups of 10 each as follows:

**Group 1-nano hybrid Group (NH):** Teeth were obturated with Gutta-percha pellets (DiaDent) using resin-based sealer (AH Plus sealer, Dentsply) till the level of CEJ. Cavities were etched for 15 seconds using 37% Ortho-phosphoric acid, rinsed for 10 seconds, and blot-dried. A bonding agent (Te-Econom Bond, Ivoclar Vivadent) was applied for 10 seconds, air dried with a slow stream of air and light cure for 20 seconds. Then the Cavities were restored with Nano-hybrid composite resin **(**Tetric N-Ceram Ivoclar Vivadent) in the incremental layering technique. The layers were placed at thicknesses of 2 mm, and each resin layer was light-cured (LED curing light, Woodpecker, China) for 20 seconds from the palatal aspect.

Group 2 – Short-fibre reinforced composite resin group (SFRC): Teeth were obturated with Gutta-percha pellets (DiaDent) using resin-based sealer (AH Plus sealer, Dentsply) to a depth of 3mm from the cervical line. Cavities were etched for 15 seconds using 37% Ortho-phosphoric acid, rinsed for 10 seconds, and blot-dried. A bonding agent ((G-Premio Bond, GC Company, Tokyo, Japan) was applied for 10 sec, air dried with a slow stream of air and light cured for 10 seconds; the cavity was restored with Short-fiber reinforced resin composite (GC Ever X posterior) in the incremental layering technique. The layers were placed at thicknesses of 2 mm and applied horizontally to ensure maximum adaptation with the floor and covered with a superficial layer of nanohybrid composite resin (Tetric N-Ceram Ivoclar Vivadent) of 1mm thickness. Each resin layer was light-cured for 20 seconds from the palatal aspect.

Group 3 – Short-fibre reinforced composite resin along with poly ethylene fibre (SFRC+PEF): After obturation of the canals, the surfaces of the access cavity were etched, and an adhesive was applied and light cured as in Group 1. The fibre was inserted into the cavity horizontally in the mesiodistal direction. Then using a plastic filling instrument, the polyethylene fibre (Ribbond Ultra 2mm; Ribbond Inc., USA) was adapted along the walls to the base of the cavity, secured in place using a flowable composite and light cured. The rest of the cavity was filled with Short-fiber reinforced composite resin and light cured. A groove of 2 mm wide and 1 mm depth was prepared on the palatal surface of the restoration in an Inciso -gingival direction. After etching and bonding the groove, a piece of polyethylene fibre (Ribbond Ultra 2mm; Ribbond Inc., USA) was adapted to the floor of the groove using a flowable composite was light cured for 40 seconds, and covered with a superficial layer of nanohybrid composite resin (Tetric N-Ceram Ivoclar Vivadent) of 1mm thickness and each resin layer was light cured for 20 seconds from the palatal aspect.

Periodontal ligament simulation was done with polysiloxane impression material (Reprosil, Dentsply, Switzerland) and then mounted vertically in self-cure acrylic resin upto the level of 2 mm below the Cemento enamel junction for all the samples. Prepared samples were positioned using a custom-made mounting jig so that a compressive load of 0.5mm/min was applied with a tip positioned at an angle of 1350 to the long axis of teeth until fracture (sudden drop in applied force) using a Universal testing machine. The force required to fracture each specimen was recorded in Newtons(N). The data thus obtained was tabulated and subjected to statistical evaluation.

Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp. Data were explored for normality using the Kolmogorov-Smirnov Z test, which showed that data were normally distributed. The mean fracture load values were statistically analysed using One-way analysis of variance followed by post hoc analysis using Tukey’s test. P value of <0.05 was considered statistically significant for all the comparisons, and a confidence interval of 95% was taken.

**RESULTS**

The mean fracture load values and standard deviation of groups are given in table1. One-way analysis of variance (ANOVA) showed the highest mean fracture load values for Group 2(469.4800N) and the lowest mean fracture load values for Group 1 (273.8000 N). Pair-wise comparisons using Post hoc Tukey’s test showed that Group 2 (SFRC group) and Group 3 (SFRC+PEF group) had significantly higher fracture resistance compared with Group 1(NHC group). There was no significant difference in fracture resistance between Groups 2 (SFRCgroup) and 3(SFRC+PEF group). Results of the pair-wise comparison of fracture resistance are given in Table 2.

***Table 1:*** *Comparison of Mean Fracture Load Values Using One-Way Anova.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Groups** | **N** | **Mean** | **Standard Deviation** | **F value** | **P value** |
| Group 1 (NHC group) | 10 | 273.8000 | 103.35099 | 5.852 | 0.008 |
| Group 2 (SFRC group) | 10 | 469.4800 | 165.44343 |
| Group-3 (SFRC+PEF) | 10 | 451.5100 | 148.04774 |

*Table 2 : pair-wise comparison of fracture resistance using Tukey’s test*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Pair-wise comparison between groups** | **Mean difference** | **Standard Error** | **significance** | **95% confidence interval** |
| **Lower bound** | **Lower bound** |
| GROUP 1 | GROUP 2 | 195.68000 | 63.23031 | 0.012 | 352.45 | 38.9056 |
| GROUP 1 | GROUP 3 | 177.71000 | 63.23031 | 0.024 | 334.48 | 20.935 |
| GROUP 2 | GROUP 3 | 17.97000 | 63.23031 | 0.957 | 138.80 | 17474 |

DISCUSSION

Traumatic dental injuries lead to necrosis of the pulp **(22).** Most of these traumas occur between 8 to 12 years of age, especially to the permanent maxillary incisors with immature roots. The thin dentinal walls are responsible for most clinical problems related to immature necrotic teeth. Apexification followed by Root canal obturation and reinforcement is the commonly followed treatment protocol for such cases in Endodontics **(22).**

In the current study, Cvek’s stage III of root development was simulated because it is the stage at which the root-to-canal ratio in a mesiodistal dimension at the CEJ is roughly 1:1 **(20**). In Stages I and II, the shorter roots (4–5 mm) were easily displaced from the acrylic blocks during loading. In Stages IV and V, a canal diameter of 1.5 mm or less may be present, which may not be susceptible to fracture, therefore, may not require reinforcement **(21).** The restorative material was extended 3 mm below CEJ to prevent coronal microleakage and improve fracture resistance **(14).**

Group 2 (SFRCgroup) showed the highest mean fracture resistance among all the experimental groups. This could be due to the resin matrix of a Short-fiber reinforced composite with cross-linked bis-GMA, TEGDMA, and linear PMMA forming a polymer matrix called semi-interpenetrating polymer network (semi-IPN). This provides good bond strength due to the micro-mechanical interlocking between the protruding Short-fibers of everX Posterior and dentin, thereby increasing the fracture toughness of the composite resin **(17)**. The critical fibre length is the minimum length at which the centre of the fibre reaches its ultimate tensile strength when the matrix reaches its maximum shear strength. This should be a minimum of 0.5 - 1.6mm for enhanced properties of a material **(18).** The critical fibre length of the E-glass fibres in the bisphenol A glycol dimethacrylate polymer matrix lies between 1 and 2mm, which is greater than the required fibre length, enabling uniform stress distribution with less polymerisation shrinkage stress **(26,27,28).**

Mechanical testing has shown major improvements in the load-bearing capacity, flexural strength, and fracture resistance of Short-fiber reinforced composite compared with conventional composite resin **(19).** Fibre fillers in Short-fiber reinforced composite resin could stop crack propagation and provide a multidirectional isotropic reinforcement effect with the greatest reinforcement efficiency, resulting in increased fracture resistance of composite resin **(17).** In the current study, Short-fibre reinforced composite was used in a bilayered technique, where a base of Short-Fibre reinforced composite extended 3mm below CEJ, and the surface layer of conventional nanohybrid composite was used as post-endodontic restoration. The advantage of this bilayered restoration was its ability to mimic the natural behaviour of enamel and dentine by its supportive function during loading and acts as dentine replacing material **(26).**

The pair-wise comparison showed that Group-3(SFRC+PEF group) had a significantly higher fracture resistance than Group-1(NH group). Ribbond is a reinforced ribbon made of a leno-woven, ultrahigh molecular weight polyethylene fibre. Leno-weave is a unique pattern of cross-linking with locked-stitched threads that increases the material's durability, stability and shear strength. **(23)**This material has been reinforced with cold gas plasma to increase its bonding to restorative materials. The unique fibre network in this material effectively transfers the forces acting on it. **(24)** The use of poly ethylene fibre in two different directions along with a Short-fiber reinforced composite could have contributed to the significantly higher fracture resistance compared to Group 1.

Among Groups 2 and 3, SFRC group showed higher mean fracture load values.This could be because of the Coronal position of post-endodontic restoration in Group 3, which could not reinforce the cervical and root part of the tooth. The elastic modulus of filling materials such as Gutta-percha presents little or no capacity for reinforcing roots after treatment as the modulus of elasticity of Gutta-percha is only 77 MPa which is much lesser than the modulus of elasticity of dentin which is approximately 16 Gpa**,** The difference in elastic moduli of the restorative materials can lead to non-uniform stress development. **(29, 30,31)**

The limitation of the present study was that all the teeth used in the study were mature teeth collected from adult patients; the structure and physical properties of immature teeth are different from mature teeth, which could limit the applicability of this study. Future studies should be conducted with Finite element analysis, and Long-term clinical studies of reinforced teeth will help to increase understanding regarding this concept of reinforcement.

**CLINICAL SIGNIFICANCE**

The newly proposed technique of fibre reinforcement in the present study (SFRC+PEF) improved the fracture strength of endodontically treated teeth compared to those restored with composite resin. Hence, this technique can be considered a conservative approach for restoring endodontically treated immature anterior teeth.

**CONCLUSION**

Within the limitations of the present study, it can be concluded that Intra-coronal and intra-radicular reinforcement using Short-fibre reinforced composite and Intra-coronal reinforcement using a combination of poly ethylene fibre with Short-fibre reinforced composite showed significant improvement in fracture resistance of immature permanent teeth after apexification.

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